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ON THE POLARIZATION MECHANISM IN THE R MON / NGC 2261 COMPLEX

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ABSTRACT. We report the detection of circular polarization in R Mon and NGC 2261. This detection implies that the mechanism responsible for the linear and circular polarization is most likely multiple scattering in a flattened distribution. It replaces the previously suggested scenario where dichroic extinction by elongated dust grains aligned by a toroidal magnetic field was producing the polarization. The multiple scattering interpretation of linear polarization maps also means that these maps now provide *direct* evidence for a circumstellar disk around R Mon and possibly around many other YSO's.

I. INTRODUCTION

It is generally admitted that NGC 2261 is a reflection nebula, the illuminating source being R Mon. Evidence for this comes from the centrosymmetric pattern of the measured linear polarization vectors (Gething et al. 1982; Aspin, McLean, and Coyne 1985; Warren-Smith, Draper, and Scarrott 1987). All the vectors lying perpendicular to the radial direction to R Mon. Such a centrosymmetric pattern is typical of reflection nebulae where single scattering is responsible for the polarization since the polarization vectors are usually perpendicular to the scattering plane.

However, departure from this simple scattering pattern is clearly seen in a band close to and including R Mon itself. In this band the polarization vectors are roughly perpendicular to the symmetry axis of the bipolar nebula. The presence of such a region of aligned polarization vectors is common in YSO's associated with reflection nebulosity (Bastien 1988).

Until recently, these patterns of aligned polarization vectors were usually interpreted in terms of dichroic extinction by elongated grains aligned by a toroidal magnetic field. However, whether or not such a field actually exists is not yet clear. Competing scenarios where the magnetic field is poloidal rather than toroidal have been proposed by Pudritz and Norman (1983) and Pudritz and Silk (1987).

We do not feel however that aligned grains are the answer to the problem. In fact, multiple scattering polarization models of YSO's (Bastien and Ménard 1988) show that the linear polarization maps of all YSO's can be interpreted as due to single scattering in two optically thin bipolar lobes combined with multiple scattering around an optically thick equatorial disk. Single scattering in the optically thin lobes naturally gives a centrosymmetric pattern while the large optical depth in the equatorial disk ensures multiple scattering. The model makes no assumption about the grain size and shape and requires no magnetic field. It also predicts a typical circular polarization pattern.

In an attempt to confirm the validity of our model, we made circular polarization measurements of R Mon and its nebulosity NGC 2261. R Mon is a good candidate for such an experiment since it is a bright reflection nebula already suspected to have a disk.

II. OBSERVATIONS AND DISCUSSION

The observations were made on 1988 January 22, 23 and 27 with the 1.6m Ritchey-Chrétien telescope of the mont Mégantic Observatory in Québec, Canada. The circu-

lar polarization data are given in Table 1. Instrumental and/or interstellar origins for the detected circular polarization can be rejected for various reasons. These reasons include a null detection at position 1 and different signs for the circular polarization of R Mon when measured with two different diaphragms. (see Ménard, Bastien and Robert 1988 for details).

We are then left with a circumstellar origin for the polarization. To explain the data, the linear polarization maps and the circular polarization, one can readily show that elongated grains are not suitable. They cannot be responsible for both the aligned linear polarization vectors and the circular polarization at the same time. If *extinction by aligned elongated grains* is invoked to produce the circular polarization then the direction of alignment of the grains has to rotate across the nebula (Kemp and Wolstencroft 1972; Bandermann and Kemp 1973; Martin 1974) and the linear polarization vectors are not aligned anymore. The large amount of extinction needed to produce the high linear polarization observed also suggests that multiple scattering is present.

On the other hand, if *scattering on elongated grains* is considered we have the same problem. Scattering on such grains could produce the circular polarization but then the polarization vectors would be centrosymmetric.

Consequently, we are left with multiple scattering in a flattened distribution, a disk, to explain the data. This mechanism can easily explain the aligned vectors in the linear polarization maps but also offers an easy explanation to the circular polarization. Further support for multiple scattering is also coming from the discovery of a halo, bluer than the star, surrounding R Mon (Beckwith *et al.* 1984).

We therefore suggest that R Mon has positive (right handed) circular polarization as detected with our 3.9" diaphragm. The equatorial disk begins to dominate the polarization at an angular size between 4" and 8"(as inferred from our measurements of R Mon with these two apertures). This thick equatorial structure governs

the production of linear and circular polarization close to the star via multiple scattering (evidence is coming from the aligned linear polarization vectors and circular polarization at position 3 and 4, and marginally at position 2, see Figure 1). Farther away from the star, where the density is lower, single scattering is responsible for the polarization. We can see a centrosymmetric linear polarization pattern and detect no circular polarization at position 1.

At this point we must note that, even though we do not detect exactly the typical circular polarization pattern predicted by our model, we clearly detect an effect caused by multiple scattering in the region around R Mon where the density is enhanced when compared to the bipolar lobes.

This region corresponds to a probable optically thick equatorial disk but is somewhat larger than the inferred 6" upper limit of Sargent and Beckwith (1987) based on Owens Valley Radio Interferometer maximum resolution. It is however much smaller than the ^{12}CO counterpart of this equatorial disk (Cantó *et al.* 1981).

In summary, the fact that the detected circular polarization can be explained *only* by multiple scattering in an equatorial disk and that all linear polarization maps can be interpreted easily by the same model provide direct evidence for the presence of a flattened structure around R Mon.

A more detailed account of the observations will appear in the 1988 December 1st issue of Ap.J.

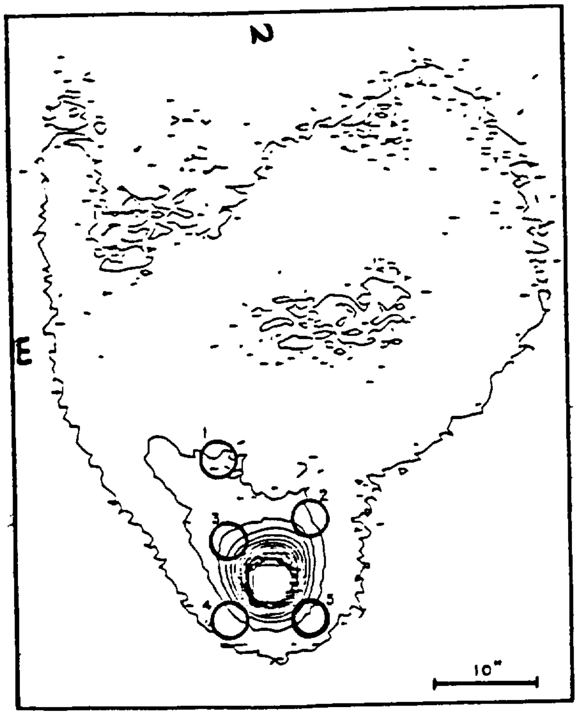

Fig.1 Isophotal contour map of R Mon. Position of circular polarization measurements are shown to scale.

Table 1

Circular polarization data for R Mon and NGC 2261

Position	ϕ_d	V/I	$\sigma(V/I)$
	°	10^{-4}	10^{-4}
R Mon	3.9	10.9	2.2
R Mon	8.3	-13.5	1.3
1	3.9	-1.2	4.5
2	3.9	-16.8	6.3
3	3.9	-20.4	6.7
4	3.9	-37.2	5.6
5	3.9	-11.1	6.2

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